Enhancing Dynamic Student Learning by Teamwork in Innovative Projects at an Erasmus Mundus Master Subject Adapted to the EHEA (EEES)

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1. SUMMARY:

The EHEA (EEES in Spain) is creating common academic degree standards comparable and compatible between the European countries. The definition of the new Credit unit, the ECTS, focused on the hours of study devoted by the students, is also promoting the renovation of the educational process at the higher studies of Graduate Degree and Master.

We describe the experience of innovation of the teaching practice of the "Fibres & Telecommunications" subject of the Master PhotonicsBCN (part of the Erasmus Mundus Master EUROPHOTONICS), by introducing team-working techniques for promoting: the development of cooperative learning, interpersonal skills, and positive interdependence among the students, not forgetting the individual initiative and responsibility.

The teamwork is oriented to small innovation projects (inspired in state-of-the-art research challenges faced by the European FP7 EURO-FOS Network-of-Excellence) promoting interactive and dynamic student learning process. Each team member is spontaneously encouraged to learn as much as possible on both: the area of his task inside the common project, and also the influence of his task in the overall results of the project. This is implemented by the

use of commercial software for professional systems deployment (VPIphotonics^{TM}), which allows each team to check the real viability of their innovative solution.

2. KEYWORDS Teamwork Learning (Aprenentatge en equip), Learning by Innovation Projects (Aprenentatge mitjançant projectes d'innovació), European Higher Education Area (EHEA - EEES) (Espai Europeu d'Ensenyament Superior (EEES))

3. DEVELOPMENT:

a) Objectives

The objective is the adaptation to the European Higher Education Area (EHEA) of a subject of the Master PhotonicsBCN, by methodologies oriented to enhance the dynamic learning of the students. This Master is jointly implemented and offered by three universities and one photonics research institute in the Barcelona: Universitat Politècnica de Catalunya (UPC), Universitat Autònoma de Barcelona (UAB), Universitat de Barcelona (UB), and Institut de Ciències Fotòniques (ICFO). The Master aims at educating future professionals and potential researchers in this field and also promoting entrepreneurial activity amongst its students [PhotonicsBCN].

The PhotonicsBCN Master is part of the Erasmus Mundus Master Course (EMMC) and Joint Doctorate (EMJD) programs in Photonics Engineering, Nanophotonics and Biophotonics: Europhotonics, organized by: the Paul Cézanne Aix Marseille III University (France), the Karlsruhe School of Optics & Photonics (KSOP), Karlsruhe Institute of Technology (KIT) both in Germany, and the already mentioned universities of Barcelona offering the PhotonicsBCN Master. The Europhotonics EMMC provides an extensive Master program focusing on advanced research and applied topics, so that the students will be able to work on today's new challenges in their applied research or academic careers [Europhotonics EMMC].

The PhotonicsBCN Master is adapted to the EHEA by introducing the new credit system and, most important, orienting the activities of the subjects to the educational process of the students, also enhancing the development of interpersonal skills in teamwork, and cooperative learning.

The experience of innovation of the teaching practice reported in this paper refers to a subject of the PhotonicsBCN Master in the area of Signal Theory and Communications named "Fibres & Telecommunications" [Fibres and Telecom]. We can summarize the general formative objective of the subject as:

"Knowing the techniques and technologies for generation, reception and transmission of optical signals through fibres and its application to fibre-optical communications systems"

covering the topics of: light propagation in fibres, optical transmitters and receivers, lightwave systems, optical amplifiers and multichannel systems and networks.

Analysing the main objectives of the subject, it would correspond to the cognitive categories of remembering and application of the Bloom's taxonomy [Anderson 2001]. The main objective is comprehended in a set of more specific objectives that expand the set of Bloom's categories, not only cognitive, but also affective domain, and partially some categories of the psychomotor domain.

b) Description of the work

We briefly describe the commented set of specific objectives just for facilitating the comprehension on how the introduced dynamics for interactive student learning by teamwork is fulfilling the proposed specific objectives.

In fact, one the of the useful tools used for enhancing the dynamic student learning is presenting at the first classes of the subject this set of specific objectives. This helps the students to orientate their efforts. On the other hand, it motivates the students, as they can better understand the final goal: to conceive and design an innovative fibre-optic communication system fulfilling strong demands and having a cost-effective requirement. For some students this can generate some scepticism, nevertheless it has to be pointed out that the set of objectives are organized for increasing their own capabilities towards reaching this final and ambitious goal. Here an application of the Pygmalion method [Jamieson 1987], [Kierein 2000] is therefore done. Creating those superior expectations of the abilities of the students promotes the real manifestation of those superior skills.

Those specific objectives for step-by-step development of the student skills and capacities are:
Objective 1): to know and identify the basic elements and devices of optical communications systems. (cognitive category of remembering)
Objective 2): to interpret and / or predict the potential causes of signal quality degradation of signals transmitted by optical fibres. (cognitive category of remembering and understanding)
Objective 3): to compare and differentiate between different types of fibre-optic transmitters, receivers, optical amplifiers and various elements of regeneration and distribution of optical signals, and to select the most suitable for the characteristics of various communications networks (cognitive category of understanding)

Objective 4): to apply the knowledge acquired to the design of an optical communications systems. (cognitive category of application)

Objective 5): to conceive and design a specific system solution by teamwork of the proposed project, minimizing the cost of the network deployment (CAPEX) and maintaining specified levels of signal quality. (cognitive categories of application and synthesis and also affective and psychomotor domain categories deriving from the team work as: receiving and responding to phenomena, valuing, organization and origination)

Objective 6): to describe, justify and argue the network design obtained by the team to the rest of students. (cognitive categories of analysis and synthesis)

Objective 7): to evaluate and judge the network design proposed by other teams, finding the advantages and drawbacks of the other proposals. (cognitive categories of analysis and evaluation)

In order to reach the proposed objectives, two main tools are used. On one hand, due to the diverse background of the students, first classes are required for introducing the basic concepts on signal theory, transmitters, receivers and transmission in optical fibres. This introduction is done by the professor with the help of a set of slides, and also supporting materials, explaining those concepts in an introductory way, are provided to the students by the use of the distant learning platform ATENEA [Atenea]. This platform permits the students to revise a set of units provided by manufactures of professional software for optical communication systems as VPIphotonics^{TM} [VPI Univ Program]. They can check by a set of questionnaires their comprehension of the introduced topics.

On the other hand, it is stated from the beginning of the course the final objective of working in teams in an innovative project. It can be also a small research project, if some of the Master students are also starting their research initiation towards their PhD.

Once the basic concepts of the subject are introduced, it is proposed to start the teamwork, in groups of 3 students, as much heterogeneous as possible regarding their previous background. As the subject is part of an Erasmus Mundus Master, students having diverse previous degree studies access to the Master course. The overview statistics of the students are shown in Table I, regarding the origin and gender, and in Table II, correlating the origin and the access Degrees to the Master. As it can be seen in Table I, this subject of the Master is mainly chosen by male students, and more drastically for Non-EU students. On the other hand, though most of the students are accessing to this subject of the Master from an engineering previous Degree, but also a significant percentage of students (40%) are accessing to this subject of the Master from other degrees. This is a challenge for the professor, as during the first sessions of the subject it is required to provide a review of some background topics for reaching a common knowledge level

by the students (also identifying students that would need extra tutorial attention from the professor and / or providing extra supporting material) in order to develop the objectives of the subject.

Table I: Origin and gender of the students

	Male	Female	Total
EU	53%	27%	80%
Non-EU	20%	0%	20%
Total	73%	27%	100%

Table II: Origin and access degree to the Master

	Engineer	Physicists	Other degrees	Total
EU	47%	7%	27%	80%
Non-EU	13%	7%	0%	20%
Total	60%	13%	27%	100%

Once the groups are formed, the theoretical classes, where the set of concepts included in the curriculum of the subject are introduced, and the teamwork are interleaved. We can describe the evolution of the subject as following the next chronogram Table.

Week	1st week session (2h) (mainly theory, introduction of concepts and materials for further study)	2nd week session (2h) (mainly teamwork in innovative projects)
1st	Introduction of the subject and its objectives	Introduction of basic concepts for levelling students' background on fundamental elements of optical communication notions.
2nd	Finishing the introduction of the basic concepts (transmitters, receivers and transmission media) for levelling and solving doubts.	1st tutorial project (in teams of 3 students) using the commercial software and getting familiar with the supporting material.
3rd	Theoretical lesson introducing the main impairments in transmission of signals	Finishing the 1st tutorial project (in teams of 3 students) so that they all have an overall view of the functionalities and performances of the 3 main elements: transmitter, receiver and transmission media.

After these 3 first weeks of the subject, all the students have achieved the objective 1 (knowing and identifying the basic elements and devices of optical communications systems) and they are partially achieving objective 2 (interpreting and / or predicting the potential causes of signal quality degradation of signals transmitted by optical fibres.) as they have started to experiment, using the software for simulation, the kind of impairments arising as the target transmission distance increases.

It is also relevant that the students can by themselves check that they have achieved objective 1, as they can manage simple fibre optic communications systems designs proposed at the tutorial project. They can also check their progress in objective 2 by answering the questions of the tutorial about the possible causes of the degradation of the transmitted signal and checking their answers with the ones of the supporting material.

Once those first objectives reached, the final teamwork project is proposed the next week.

Week	1st week session (2h) (Mainly Theory, introduction of concepts and materials for further study)	2nd week session (2h) (Mainly Teamwork in innovative projects)
4rd	Theoretical lesson introducing the fundamental reasons of the impairments and degradation of signal by transmission (Part I).	Detailed description of the final project, e.g. distance to be covered by the network, transmission capacity in number of channels, bit rate of the channels, and any other relevant characteristic of the project.
5rd	Theoretical lesson introducing the fundamental reasons of the impairments and degradation of signal by transmission (Part II).	Time for Teamwork. First attempt of the teams in solving the proposed project.

At this moment it is important that both theoretical lessons and teamwork at the project are well synchronized. At the theoretical lessons main impairments of transmission of signals in optical fibres are being described. Sometime, thought using graphical representation of the impairments, they are difficult to visualize and identify. During the teamwork at the project, many difficulties are arising. It is important to clarify to the students that it is a first attempt to solve the project and at this moment the most important is to identify the difficulties that they are facing. The attempt of resolution of the project has the following benefits for the learning process of the student:

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a) the students can check that the capacities that they are in the process of developing by the subsequent achievement of the proposed objectives are relevant, as just having the software for design and managing the basic elements of communication networks is not enough;

b) they are visualizing and experiencing the kind of impairments that are being described in the theoretical sessions.

By the synchronization of the theory and project work, an important enhancement of the dynamic student learning is achieved, and the students start to autonomously following the proposed material for further study.

Still more, the next section of theory focuses on the alternative techniques and technologies, historically, nowadays commercially or currently under R&D process used for overcoming the transmission impairments and increasing the distance and capacity of optical networks. The contact of the students with real projects enhances the engagement of the student in the learning process.

The next week is the most relevant for a strong intensification of the dynamic of the teamwork.

Week	1st week session (2h) (Mainly Theory, introduction of concepts and materials for further study)	2nd week session (2h) (Mainly Teamwork in innovative projects)
6rd	Theoretical lesson introducing techniques and technologies, commercial or under R&D process for overcoming the transmission impairments (Part I).	Exposition of the different teams about the achievements and main difficulties faces during the first attempt of solving the proposed project.

At his time, the students may have the impression that the alternatives of possible solutions increase significantly and that the proper resolution of the project requires an enormous effort out of the assigned number of ECTS (during the previous weeks, added to the hours devoted to lessons, supporting material and further study material is being followed by the students).

This difficulty can be converted in a positive feature by introducing specialization and cooperative learning (positive interdependency, among the members of each team and individual and group accountability [Kagan 1994]). The main work of the design of the network can be divided in 3 main topics: a) transmitters (TX) and receivers (RX); b) transmission in optical

fibres; c) optical amplification and signal distribution technologies and devices. It is then proposed to each team to decide among the members how are they going to distribute the specialization topics. At this point it is relevant the previous heterogeneous distribution of students. Typically, engineers of telecommunication tend to choose specialization on transmitters and receivers as this is closer to the previous background, while physicists usually choose specialization on fibre transmission or optical amplification. Nevertheless, some students prefer to choose not their closer topic, but the opposite for better completing their knowledge and skills, which has to be also taken into account when evaluating the final results of the project, as it has not to be forgotten that the final objective is the learning process of the students, more importantly than the technical resolution of the proposed project.

The Figure 1 and Table III show the evolution of the proposed teamwork sessions (both are showing an example for e.g. 9 students distributed in 3 groups, but a higher number of students could also be managed). The first 2 stages of the teamwork have been already done (working the tutorial project and performing a first attempt to solve the final project as a team). The main objective of the table III is a clearer explanation of the specialization process. For a set of several weeks, the corresponding student 1s (St. 1) of each team groups in new groups of 2 or 3 students, for commonly working in learning as much as possible on their specific topic.
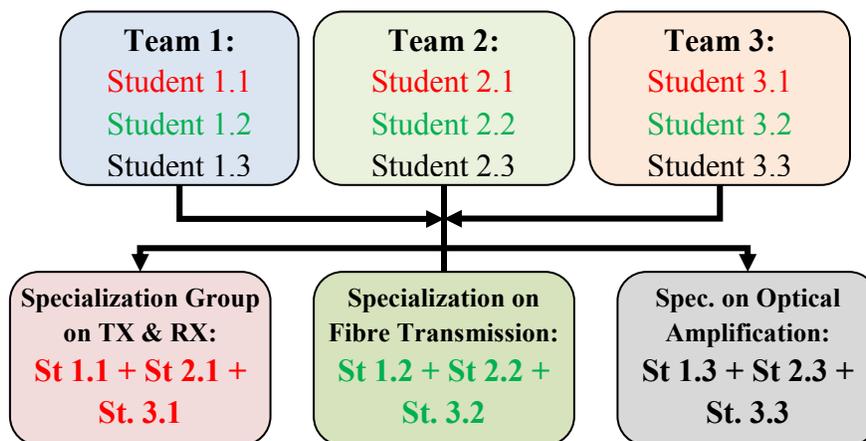
Fig. 1: Distribution of students in Project Teams 1 to N, and redistribution of the students for the specialization process.

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Table III: Teamwork sessions overview.

Teamwork sessions			Team 1			Team 2			Team 3		
			St.1	St.2	St.3	St.1	St.2	St.3	St.1	St.2	St.3
Tutorial project			X	X	X	X	X	X	X	X	X
1st attempt to solve the final project			X	X	X	X	X	X	X	X	X
Specialization	on TX & RX		X			X			X		
	on Fibre Transmission			X			X			X	
	on Optical Amplification & Signal distribution				X			X			X
2nd attempt to solve the project, with economical constrains			X	X	X	X	X	X	X	X	X
Presentation of the network design, innovation, performance and cost-effectiveness			x	X	x	X	x	x	x	x	X

*: The differences between capital and lowercase cross-marks to be explained later in the text.

The specialization process is developed also in team work, (groups of 2-3 students) following a set of material oriented to simulation practices using the commercial software. For developing this task the Pair Programming technique is used.

The Pair Programming technique requires that each student performs an activity the other is not doing now: As one student is developing the simulation, the other one thinks on how this simulation will help to answer the question proposed at the script for the simulation exercises. The student developing the simulation (the navigator) and the student who is directing and managing (the controller) are impelled to change their roles every half hour.

This technique provides a certain number of advantages for the realization of the proposed specialization practices: a) It generates more discipline in the implementation of the practices; b) Better results are generated; c) It promotes a consistent and continuous workflow; d) It promotes a positive interdependence as the results of the practices include more directly the work of both students; e) This technique grants that both students, whether they have more experience or

knowledge engage alike, favouring a greater sharing of knowledge of students. A recent study shows that novice pairs against novice solos are much more productive than expert pairs against expert solos [Lui 08]. So, for this case, where students are in their initial learning phase and according to this study, it is expected that the performance of the simulations practices will be significantly improved by team working and pair programming.

The materials for this specialization process of the members of the team are:

a) the introductory and also the more specialized material explained during the class sessions devoted to theory
b) the material and bibliography material recommended for further study
c) the manuals of the professional software, extensively describing the models, functionalities and performances of the diverse elements of the optical network
d) specifications of commercial products that can be used for modifying the model that describes by default the performance of the elements of the optical network in the commercial software.

At this point, it is important to introduce the techno-economical aspect of the project. On the one hand, it promotes a relevant aspect of any real innovation or research project. On the other hand, this can be converted in an extra tool for stimulating the learning process of the student. This can be better explaining using an example. E.g. for the students that have chosen the optical amplification as specialization topic, the professional software tool of design of optical networks, offers a set of models of optical amplifiers as shown in Table IV [VPIphotonics]:

Table IV: Example of different optical amplifiers models and approximate cost.

Module representation	Description	Assigned price /Difficulty
Ideal	This model corresponds to an Erbium Doped Fibre Amplifier (EDFA) with self-control of gain, output power and internal equalizer. It provides an ideally flat and controlled gain or output power.	40.000€ Low difficulty
Pump / Black Box	Correspond to a commercial EDFA that would require a manual adjustment of pumping level. This module simulates an optical amplifier using a black box model, based on data that can be obtained experimentally from a commercial EDFA.	5.000€ Moderate difficulty
RateEqStat	This module simulates a subsystem EDFA by their rate equations of the population of different energy levels of ions. The subsystem includes bidirectional pumping source, filter and polarizer.	2.000€ High difficulty
DopedFiber	This version represents as if you would buy the items individually and build an EDFA by yourself. The model simulates an EDF based on the equations of bi-directional signal propagation and rate equations.	10€/m High difficulty
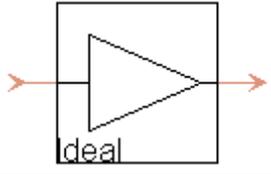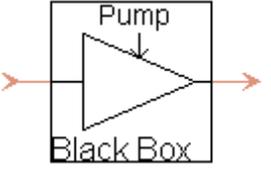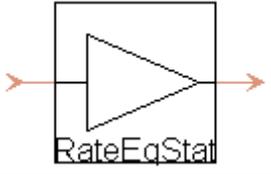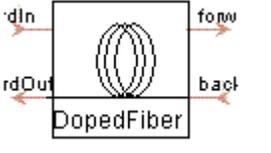
*: It is possible to buy EDF at a price of 3€/m (the rest of passive component can be considered having a cost o 200€).

The simplest models are very easy to manage in a network and would corresponds to very expensive equipments including a important and costly electronic management and control of the amplifier able to provide the best performance of the amplifier even in the most demanding conditions. On the other extreme, the software also provides, very detailed physical models of the elemental components acting as main elements of optical amplifiers. Those elemental components, at a basic component level, are much cheaper. Correspondingly, a set of prices has to be given to each group of specialist as a relevant element for the cost evaluation of the project solutions that would find each team. In this way, both more realistic and techno-economically

viable solutions could be found and this feature also will enhance to each group of specialist to look for the best trade-off between cost and complexity of the implemented solution.

Proposing a techno-economical approach provides a straightforward path for approaching innovative projects to most recent research and commercial technologies. As two possible examples, promoting the use of more realistic and realistic models of the optical amplifiers as the Black Box Model or the model based in individual components and a "make-by-yourself" procedure, provides a valuable update of the innovation projects and the learning experience of the students to current state-of-the-art research joint projects of European 7th Frame Program (7FP) EURO-FOS and the software and characterization facilities (e.g. of optical amplifiers) provided by EURO-FOS virtual laboratory [Eurofos Lab].

After the process of specialization, each student meets his initial working group for the proposed project, this time with a much larger background of knowledge that should ensure good resolution of the project.

The positive interdependency is implemented by the Jigsaw Puzzle technique [Aronson 1997] as no team can achieve solving the proposed project if any of its members have not become an "expert" in his own field. On the other hand, the best innovative and cost-effective solution depends on the particular learning effort of each member of the team.

Next Figure 2 shows an example of the technical results obtained by one of the teams, showing the scheme of the simulations and the quality of the transmitted optical signals by the eye diagram of the signal.
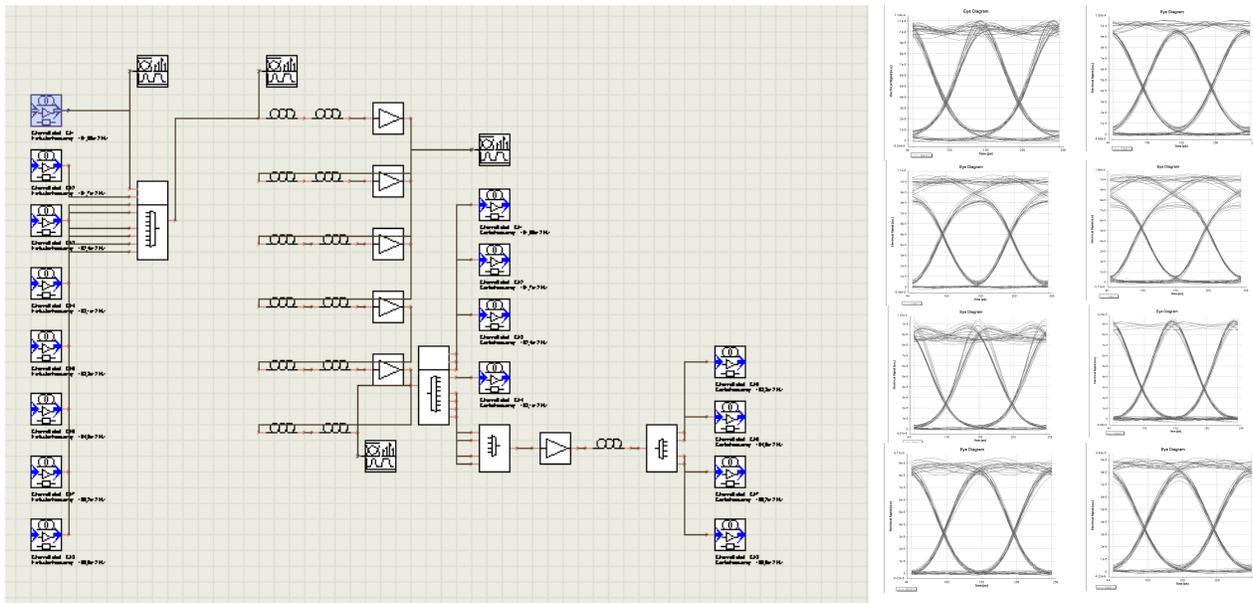
Fig. 2: Example of one of the results of proposed project, showing the scheme and performance, reaching the specified distance still maintaining the adequate level of quality of the signal

The final stage is the presentation and discussion of the solutions, the "Presentation of the network design, innovation, performance and cost-effectiveness" session, shown in Table III. The presentation is done by a member of the group, chosen at random the day of the presentation each group for the project presented. (The capital "X" in table III in session "Presentation of the network design, innovation, performance and cost-effectiveness" means that this student is performing the presentation that day, while the other students of the group are represented by a smaller "x".)

The evaluation of the projects will be performed by both the professor and the students themselves. For this evaluation, it was agreed in advance by the professor and the students, the quality criteria according to which the projects will be evaluated.

On one hand, the objectives of the project were clearly defined at the beginning of the course. For example, for this currently course, the specific objectives were:

Design and test by simulation of a WDM point to point link, transmitting 8 channels at 10 Gbps, covering a distance of 600 km.

This definition of the project is complemented by a precise definition of the objectives of the project:

i.) Level of quality of the transmitted signals: all the channels have to provide a Bit Error Ratio (BER) $\leq 10^{-9}$.

ii.) The design of the proposed network should be able to provide the required quality of transmission at the lowest cost.

iii) In case, the designed/proposed WDM transmission link outperforms the required distance or transmission capacity, in a general way, the design should maximize the function: (Capacity x Distance) / Cost.

During this course the quality criteria, used by all participants at the Fibers and Telecommunications course for evaluating the final projects are shown in Table V. They were proposed in a draft version by the professor and revised by students, so that finally a consensus was found.

Table V: Quality criteria used by students and professor for evaluating the presented projects.

Quality level			
Criteria / Score	**3**	**2**	**1**
Main objectives of the project reached	The main objectives of the project have been achieved: BER ≤ 10^{-9} for <u>all channels</u>.	The main objectives of the project have been partially achieved: <u>some channels</u> do not reach BER ≤ 10^{-9}	The main objectives of the project have not been achieved: <u>none</u> of the channels reaches BER ≤ 10^{-9}
Price	The presented project reaches the main objectives of the project <u>at the lowest price</u> among the presented projects.	The presented project reaches the main objectives of the project, but <u>not at the lowest price</u> among the presented projects.	The presented project reaches the main objectives of the project, but <u>at the highest price</u> among the presented projects.
Innovation level	The presented project shows <u>several</u>	The presented project shows at <u>least one</u>	The presented project <u>does not include any</u>

	innovative solutions for reaching the main objectives of the project.	innovative solution for reaching the main objectives of the project.	innovative solution for reaching the main objectives of the project..
Extra performance	The solution of the project demonstrates a clear extra performance, overcoming the main objectives of the project, e.g. higher capacity or covered distance, or extra margin in BER.	The solution of the project demonstrates a moderate extra performance, overcoming the main objectives of the project, e.g. higher capacity or covered distance, or extra margin in BER	The solution of the project does not demonstrate any extra performance than the main objectives of the project, neither in higher capacity, covered distance, nor extra margin in BER
Cost-effectives	The project demonstrates the best cost-effectiveness of the presented project, showing the highest value of the merit function: (Capacity x Distance) / Cost	The project demonstrates a good cost-effectiveness of the presented project, but not showing the best value of the merit function: (Capacity x Distance) / Cost	The project does not demonstrate a good cost-effectiveness of the presented project, showing the lowest value of the merit function: (Capacity x Distance) / Cost
Presentation of the project	The project has been clearly presented and explained.	The project has not been clearly presented or explained at some of the technical or techno-economical aspects.	The presentation of the project is difficult to understand and / or the explanation of the project is difficult to be followed.

Table VI: Example of the techno-economical results presented by the students:

Team 1: Budget of the simulated Optical Fibre Transmission Link

COMPONENT		PRICE
TRANSMITER		
	LASER CW	8 X 100€

	MODULATOR AM	8 X 1000€
	WDM	100€
TRANSMISION MEDIA		
	FIBER NLS	2€/KM X 501 KM= 1002 €
	FIBER DC	10€/KM X 100 KM = 1000€
	AMPLIFIER IDEAL	40.000€ X 5 U= 200.000€
RECEIVER		
	PIN PHOTODIODE	8 X 100€
TOTAL		**211700 €**
	Capacity*Distance/Cost	8X10Gb*600km/15810 =**0.227 Gbps*Km/€**

Team 2: Cost

		Price	Units	Total
Transmitter				
	Laser CW	100,00 €	8	**800,00 €**
	Mod AM	1.000,00 €	8	**8.000,00 €**
	Rx	100,00 €	8	**800,00 €**
Amplifiers				
	AmpliSysOpt (Ideal)	40.000,00 €	6	**6.000,00 €**
Optical fibres				
	Universal Fibre	1,00 €	563	**563,30 €**
	DCF	10,00 €	50,1	**501,00 €**
				250664,00 €

Capacity*Distance/Cost = 0.191 Km * Gbps / €

Thought not explicitly shown, all the projects presented fulfilled the main objectives of the proposed project: the 8 channels provide a Bit Error Ratio (BER) $\leq 10^{-9}$.

In order to comment a little bit about the results presented by the students, we will focus on the small exercise on the techno-economical analysis and innovation done by the students. As it can be seen in Table VI, both projects presented similar solutions.

As innovation, the Team number 1 decided to work with a special transmission fibre. It has a higher cost, but they were able to compensate the extra cost by reducing the number of optical amplifiers required for the link. The Team number 2 decided to work the cheapest standard transmission fibre. Though this fibre is cheaper, they required using an extra optical amplifier resulting in a total higher cost. (It has to be noted, that no civil work expenses have been considered, as they are more difficult to evaluate, usually very high cost and at the end, considered a common and expense for all the projects presented).

Thought not relevant to get into details, for the interest of this communication, it is interesting to be noticed that during the evaluation session of the projects, it was acknowledged and evaluated that Team 2 was providing a technically more innovative solution, thus providing a higher margin (or alternatively, a significant extra distance could be provided than the Team 1). Nevertheless, the Team 1 did not reflect properly the benefits of their innovation at the techno-economical analysis of their solution.

This experience had a significant impact among the student. On one hand, it was a good exercise for all regarding one of the objectives of the subject: "**Objective 7):** to evaluate and judge the network design proposed by other teams, finding the advantages and drawbacks of the other proposals. (cognitive categories of analysis and evaluation)". It was also significant that even the members of the Team 2 recognized that thought their technical solution and innovative solution was better, they did not take advantage of this at the techno-economical analysis. Finally, then all students agreed that the project presented by Team 1 was the best from the techno-economically point of view, though the project presented by the Team 2 was the best from the technical and innovative point of view.

An additional aspect, also important for the students, is to stay close to the research trends in optical communications. That is the reason why an additional practice will be proposed, to introduce and understand some of the novel modulation formats. In the same way as a higher focus was put in this course on the optical amplification of signals, also the focus can be moved to the modulation formats and their relevance in the techno-economical results of a network project.

Until now, the widely used modulation format has been intensity modulation combined with direct detection. Nevertheless, the present state of the art is giving more importance to the

advanced modulation formats (e.g. optical phase modulation), reversing the previous trend. Taking advantage of the EU-FP7 EURO-FOS research network of excellence, novel ideas developed in that research network are adapted to the undergraduate level for a better understanding of the underlying concepts.

Precisely, in this case what is proposed is to evaluate by simulations a Differential Quadrature Phase Shift Keying (DQPSK) link, following the research trends [newslettersEuroFOS1], [newslettersEuroFOS2], and compare them versus the performances of a standard intensity modulation system. The points that are aimed to reach in this additional practice are:

- Understand the reasons driving to the research state-of-the-art point.

- Evaluate and quantify the differences between both systems.

Regarding the work methodology, first a theoretical study of the new system is proposed to the students of the Group of Specialization on Transmitters and Receivers (Figure 1 and Table III), previously to the simulation work. This study is a basic exercise for reaching the basic parameters of each modulation format under study, based on the theoretical background explained in the 6th week of the course. As an example, the parameters to calculate in this study can be: optical bandwidth, modulation depth and/or extinction ratio, theoretical bit error ratio, etc.
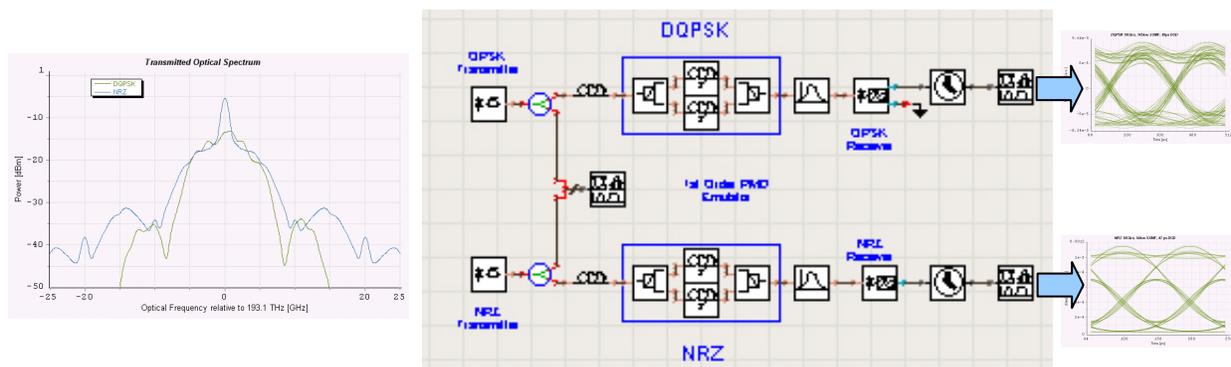
Fig. 3: Example of one of the results of proposed introductory practice in order to follow the research trends, showing the scheme and performances comparison between the two approaches (intensity modulation and DQPSK).

Afterwards, several simulations are performed in an additional practice session, while following a written outline with a questionnaire, to be filled by the students. As an example, the students are asked about different parameters of the transmission link, e.g.: maximum distance, accumulated dispersion, polarization mode dispersion, laser linewidth influence, modulation depth and/or extinction ratio, bit error ratio, etc. Also they are asked to speculate about which of these parameters have more effects on each system, in order to be aware of the strong and weak points of each approach.

The pair programming technique is also applied to this practice. In this case, the students are asked to shift their roles every half an hour. This technique gives to the students the ability to gain more knowledge of both, the simulation tool and the subject under study, as they are continuously switching from the navigator role to the controller role and vice-versa.

After this introductory practice session, the students are asked to slightly modify the project they were working on, replacing the standard intensity modulation transmitters and receivers by the DQPSK ones, which are part of the state of the art of the research. At this point the teams are asked to debate which are the improvements reached and why. Of course the improvements will be limited by the previous link design (which was optimized under techno-economic conditions), so each team will have links with different degree of performance. All this process is expected to take an entire practice session.

For this additional practice, the evaluation method is similar to the project, but with some differences. First, the introductory session is marked by the professor, in order to evaluate the degree of understanding of each team. Regarding the next session, after debating the improvements made by replacing the standard transmitters and receivers in the transmission link of the techno-economic project, each team is asked to re-evaluate the network designs of their mates, now with the new transceivers, but following the same quality level criteria as before, stated in Table V.

As future lines of development, a significant difficulty has been noticed by student in taking decisions. This can be seen in the fact that, though most of the students were analyzing different modules, e.g. optical amplifiers, for reducing the cost of the overall project, none of the Teams decided to go into more "do-it-yourself" or "low level engineered" solutions.

During the evaluation session of the projects it was seen that the some of the specialization groups faced some difficulties in taking the decision to change the module. This opens a reflexion among the professors involved in the subject about:

- If there is really an advantage in using lower level description of the modules

- Which techniques could be proposed to the students for developing this skill of choosing between several implementation alternatives

This question, relevant for developing a better learning process at the specialization sessions is under discussion and will require de development of specific tools and technique for learning in the difficult skill of taking decisions in design process.

Though Engineering is increasingly recognized as a decision-making process, [Hazelrigg1998], this recognition is just pointing out the relevance of theories and methods in economics, operations research, decision sciences, and other disciplines. This kind of skills is also relevant for relevant nowadays engineering education initiatives as Conceive — Design — Implement — Operate (CDIO), formally founded by the Massachusetts Institute of Technology [Crawley 2007] and recently presented at the Escola Tècnica Superior d'Enginyeria de Telecomunicació de Barcelona (ETSETB) [CDIO at ETSETB]. The CDIO initiative aims to better align, the teaching process at engineering and the current necessities of the companies, potential employers of the current Master studies.

The implementation of those complex theories and methods into teaching techniques for developing this king of transversal skill would be relevant and placed as objective for future work.

c) Conclusions

In this study, the implementation of educational techniques for the adaptation of a subject of the Master PhotonicsBCN (part of the Erasmus Mundus Master EUROPHOTONICS) to the EHEA ("Espacio Europeo de Educación Superior" EEES in Spain) is presented, by introducing team-working techniques for promoting: the development of cooperative learning, interpersonal skills, and positive interdependence among the students, not forgetting the individual initiative and responsibility.

The Jigsaw Puzzle technique is implemented for enhancing the autonomous student learning by the proposal of innovation or even small research projects at the subject of "Fibers and Telecommunications". The adapted innovation projects proposed for student's team working are linked and partially inspired in state-of-the-art research challenges faced by European 7FP EURO-FOS. This assures a continuous update of the innovation projects to the last techniques.

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By team working in the proposed innovative project, both at the beginning of the subject and the end, the following benefits have been found:

1) Stronger interest on the contents of the subject is generated, as the theoretical contents are evaluated as highly relevant for solving the demands of the project.
2) Autonomous and group learning has been stimulated, as it has been checked by the higher number of visits for consulting the supporting material provided by web and the extra bibliography for further study.
3) Working with innovative or small research projects, helps to introduce to the student into the current state-of-the-art in technical disciplines.
4) References and links to the research activity of European 7th Frame Program EURO-FOS stimulated the interest of students for possible collaborations in the frame of European collaborative projects and maintain an update of the proposed projects.
5) Using commercial software for the development of the innovative projects, has been significantly positive evaluated, as the students starts familiarizing and working with potential tools of their professional future.
6) The Jigsaw Puzzle technique provides a powerful tool for generating positive interdependency and personal responsibility, and provides a path for facing higher level innovative projects where the high level of work required is efficiently distributed and managed by the working team and specialization sessions.
7) A techno-economical approach is also promoted at specialization sessions as an important way to transmit the innovation breakthroughs to cost-effective solutions.
8) The results of the innovative projects, evaluated by all the participants of the subject by a consensus in the quality criteria, significantly enhance the capacity of the students to evaluate and judge projects and innovative solutions by finding advantages and drawbacks.
9) Finally, transversal skills as positive interdependency, resolution of conflicts, creativity and cooperation are naturally developed as part of the teamwork.

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